In the United States Air Force, the F-15 is today gradually being replaced by the air superiority aircraft F-22, but it still remains the primary USAF fighter designed to achieve and maintain air superiority. The F-15 is also the most effective modern fighter aircraft, with over a hundred enemy kills to its credit, while never having been defeated in air combat. Photo: USAF

Michał Fiszer, Jerzy Gruszczyński

Boeing F-15A/B/C/D Eagle

On September 30, 1968, the detailed tactical and technical requirements for the new air superiority fighter for the USAF were specified and sent to eight aviation companies: McDonnell Douglas, North American, Grumman, General Dynamics, and Fairchild-Republic. On December 23, 1969, McDonnell Douglas was announced as the winner of the competition for the aircraft design in the Full Scale Development phase, having developed the aircraft project with the factory designation model 199-B. Soon after, the USAF designated it as the F-15 Eagle.

Given the requirements, the F-15 airframe design was surprisingly conventional, without the use of the latest achievements in aerodynamics (variable-sweep wing) or futuristic technologies (titanium, special aviation fuel, long-range guided missiles). Photo: Boeing

The production contract was signed on January 2, 1970. It covered the delivery of 20 pre-series aircraft, 12 intended for tests in so-called category I (basic tests) and 8 for category II (advanced tests) and category III (operational tests). In total, the purchase of 749 aircraft was planned: 12 not fully equipped aircraft for category 1 tests; 432 aircraft intended directly for combat units, which constituted the equivalent of six wings with 72 aircraft each (three squadrons of 24) – three for TAC, two for USAFE, and one for PACAF; 108 aircraft for training and combat units; 54 aircraft that were to serve as the direct reserve for units, and 143 as the central reserve.

The first 20 aircraft received the designations F-15A (single-seat aircraft) and TF-15A (two-seat, trainer-combat aircraft). In October 1978, the designation of the two-seat aircraft, TF-15A, was changed to F-15B.

An interesting element of the design is the aircraft's wing, constructed as a trapezoidal wing with relatively little mechanization and a simple structure. In contrast to the F-4E Phantom II fighter, which was equipped with slats and rear maneuvering flaps, the F-15's wing is completely smooth, and the only movable element used for maneuvering is the aileron. The wing was optimized for maneuvering at transonic speeds, which are most typical for aerial combat.

The most typical for aerial combat. Therefore, it received a trapezoidal outline with a 45° leading edge sweep. Thanks to the use of a trapezoidal planform, a relatively large wing area of 56.5 m² was achieved. With a calculated combat weight of 16,160 kg (at which the aircraft most often enters combat), the wing loading was only 286 kg/m², which at that time was an excellent result.

As a result, the lift generated at moderate angles of attack was sufficient to produce high g-forces. Therefore, not only could mechanization be omitted, but a relatively thin NACA 64A laminar airfoil with a relative thickness of 6.6% at the root and 3% at the tip could also be used. The use of aerodynamic twist was intended to soften the stall characteristics, which could be quite abrupt with the chosen airfoil. The airfoil itself was slightly modified—the nose of the airfoil was bent downward. This created something like permanently deflected leading-edge flaps at a small angle, typical for maneuvers at transonic speeds. Maneuvering was also facilitated by small strakes at the wing-fuselage junction, generating small vortices that increased the energy of the airflow in the wing root area, which, for a trapezoidal planform with low aspect ratio, was most susceptible to rapid flow separation.

The wide fuselage of the aircraft contributed to lift generation, and its large volume allowed for the installation of complex electronic equipment and a large fuel reserve.

The F-15 was the world's first aircraft built according to the concept of relieving the pilot from monitoring the cockpit interior and dealing with airframe matters, allowing them to focus on the tactical aspects of combat. The aircraft did not yet have an active control system, but it was equipped with a highly advanced control system that worked in conjunction with conventional aerodynamic stability.

F-15 armament tests: prototype 71-0286 captured during the launch of an AIM-7E Sparrow medium-range air-to-air guided missile (October 1973) and firing the six-barrel M61A Vulcan cannon (August 1974). Photo: Boeing (2)

Working with the conventional aerodynamic stability of a classic airframe. It had a system that changed the stick-to-control surface deflection ratio depending on flight speed and altitude, as well as a system preventing the exceedance of permissible angles of attack and allowable g-forces. The entire system was integrated into the Control Augmentation System.

CAS (Control Augmentation System). A separate system was the Stability Augmentation System (SAS), which stabilized the aircraft, supplementing its natural aerodynamic stability. This system utilizing an electronic processor, stabilized the aircraft using rapid, small deflections of the control surfaces

Flight tests

The first example of the aircraft, F-15A-1-MC (71-0280), was rolled out of the assembly hall on June 26, 1972. Shortly after the ceremony, it was disassembled, loaded onto a C-5A transport aircraft, and delivered to Edwards Air Force Base. There, the aircraft was reassembled and, on July 27, 1972, it was flown for the first time by McDonnell Douglas's chief test pilot, Irving L. Burrows.

The first flight, which lasted 54 minutes, was completed successfully, but due to a malfunction in the landing gear retraction system, it was conducted cautiously, not exceeding a speed of 600 km/h and an altitude of 3,700 m. The aircraft's good handling characteristics, and above all, the resolution of the malfunction, encouraged a gradual increase in achieved parameters, and during the first week of testing, the aircraft reached a speed of Mach 1.5. The flights were conducted by two pilots—Irving L. Burrows and Peter Garrison. In further tests, the first example of the aircraft was used to study flight characteristics in various configurations, both with and without external stores. The thousandth flight was performed on it in August 1973, and by that time, it had already been flown at speeds up to Mach 2.5 and at altitudes up to 18,500 m.

Fire Control System

Work on the radar for the new fighter began in August 1968. Initially, five different radar station configurations were considered for the future F-15, but ultimately, it was decided to build a long-range pulse-Doppler radar, adapted for detecting and tracking targets both above the aircraft and against the ground, as well as for cooperation with semi-active radar-guided missiles.

Developed by Hughes Aircraft Company of El Segundo, California, the radar was designated by the USAF as AN/APG-63. The main designer of the radar was Erv Grau, now vice president of the Space and Airborne Systems division at Raytheon. It was characterized by a high detection range, reaching 240 km when detecting a large bomber flying on a head-on course. For similar

The F-15A air superiority fighter was armed with an M61A Vulcan 20 mm cannon installed in the left wing root (looking in the direction of flight), four medium-range air-to-air guided missiles: AIM-7E Sparrow, carried on external pylons located on the side edges of the engine air intakes, and four short-range AIM-9P Sidewinder missiles.
Photo: USAF

The F-15C MSIP II air superiority fighter is armed with four AIM-120A medium-range air-to-air guided missiles and four AIM-9M short-range missiles. Additional AIM-120 missiles (up to a maximum of eight) can be carried at the expense of AIM-9M missiles. Another armament configuration for the aircraft may include two AIM-7M missiles, four AIM-120s, and two AIM-9Ms. Photo: USAF

The ROC-9-98 requirements, according to which the F-X/F-15 program was implemented, were as follows:

1. A wing optimized for high load factors at a speed of Mach 0.9 at an altitude of 10,000 meters, free from flutter and buffeting;
2. A high thrust-to-weight ratio to achieve high maneuvering energy throughout the entire range of permissible flight parameters;
3. A minimum speed of Mach 2.5 at high altitude;
4. A long-range pulse-Doppler radar with the capability to detect and track targets against ground backgrounds;
5. A single-person crew capable of performing all tasks; 6. A modern cockpit with appropriate displays, including a Head-Up Display (HUD);
7. Airframe lifespan of no less than 4,000 flight hours;
8. 360-degree visibility from the cockpit;
9. High technical efficiency, with maintenance labor not exceeding 11.3 hours per one flight hour;
10. Significantly more favorable mean time between failures of avionics system components compared to equipment currently used by the USAF;
11. Airframe structure with high survivability on the battlefield, featuring redundant hydraulic systems, fuel lines, electrical systems, and dual control systems;
12. Capability for autonomous engine start without the assistance of any ground equipment;
13. Intercontinental range for redeployment of the aircraft without aerial refueling;
14. Maximum takeoff weight for intercepting an aerial target: 18,150 kg;
15. Low development risk for the airframe, powerplant, and avionics; all components must operate efficiently during testing.

For a target that is moving away, this range was about 185 km. For a fighter-type target (with a radar cross-section of about 5 m²), these parameters were approximately 180 km (for an approaching target) and 120-130 km (for a receding target). These values decreased when detecting a small target against the ground background: to approximately 120 km and 70-80 km, respectively. The radar could not detect targets flying against the ground background perpendicular to the fighter aircraft. The tracking ranges were about 60% of the above values. The radar itself, including the antenna and electronic blocks, weighed about 230 kg. The radar operates in the frequency range of 8.0-12.0 GHz. The radar's transmitter, receiver, and the processor controlling their operation were analog. The radar was equipped with an analog-to-digital signal converter and two digital signal processing processors. The radar station display was presented vertically on the cockpit monitor (top-down view like a map) and on the head-up display. The F-15, alongside the naval F-14, was the first American aircraft in which the screen did not show the "raw" radar image, but instead displayed targets using symbols with descriptions of their basic flight parameters. Therefore, two digital signal processors were used in the radar—one determined the parameters of signals reflected from targets, and the other, based on this information, separated real targets

It was resistant to interference and provided information about the flight parameters of real targets, which it transmitted to the central mission computer.

The primary search mode of the radar is Long Range Search, in which the search distance could be selected at 295 km, 150 km, 75 km, or 37 km. In this mode, the radar alternated between high and medium pulse repetition frequencies; at medium pulse repetition frequency, a long detection range was achieved, while at high pulse repetition frequency, high precision in target position determination was obtained.

The system enabled precise information to be provided for ten targets. In this mode, the radar generated a narrow forward-directed beam, with four horizontal search layers.

The mode for searching for aircraft over a wide area of airspace (up to +60° to either side of the aircraft's axis and in several horizontal layers, i.e., within an elevation angle range of +20°) was Short Range Search (SRS), in which the radar's range was limited to 20 km. In this mode, a target could be manually designated for engagement and the system could switch to Single Target Track mode. In this case, other aircraft disappeared from the display, and the tracked target was indicated to the weapon system for engagement (with missiles selected by the pilot or the system calculated parameters for firing the cannon). It was also possible for the system to automatically track the nearest target. If the armament switch on the throttle lever was set to "cannon," the system automatically switched to tracking the nearest target within the entire scanned area. If the weapon system was set to SRM (AIM-9) or MRS (AIM-7) and the pilot activated the automatic tracking mode on the control stick (one forward press of the button), the system switched to SuperSearch (SS) mode, automatically acquiring the nearest target within 20° of the aircraft's longitudinal axis, simultaneously designating this target to the seekers of the selected missiles. If the pilot selected Boresight Track (BST) mode on the control stick (two forward presses), the system automatically acquired the nearest target within 4° of the aircraft's longitudinal axis. This mode was used for semi-automatic transition to tracking mode—if friendly aircraft were nearby and the pilot wanted to manually designate a target for engagement, by selecting this mode, the pilot had to point the aircraft's nose roughly toward the chosen target, and the system would automatically begin tracking it. In the event of accidentally acquiring the wrong target, the pilot could "drop" tracking using the switch on the throttle lever. Additionally, the radar also had a Vertical Search (VS) mode, in which the antenna scanned the space in the vertical plane (conversely, +60° in elevation and +20° in azimuth), facilitating target acquisition during tight maneuvers in close air combat.

The AN/APG-63 was equipped with a range of modern anti-jamming systems: rapid frequency hopping to escape jamming, reception and analysis of signals in the side lobes with electronic elimination of false echoes, frequency diversity system, etc.

In addition to the functions mentioned above, the radar could also be used for range measurement when engaging ground targets, as well as for navigation purposes—primarily Doppler measurement of true airspeed and drift angle, and for mapping (for navigation, but not targeting). There was also a mode for homing on the beacon of an aerial tanker, as well as a passive mode that supported the aircraft's electronic warfare system (as described later).

All data from the radar station was displayed on the McDonnell Douglas Electronic AN/AVQ-20 Head-Up Display (HUD) and on the tactical situation display. In addition to the radar, the aircraft was equipped with a radar transponder with both civilian and military modes, including the so-called mode IV used for "friend or foe" identification. This device was the Hazeltine AN/APX-76.

Self-defense system

It was assumed that the F-15, used for offensive missions in which it was to engage aerial targets over enemy territory, must be equipped with an electronic warfare suite typical of a strike aircraft. This was the first standard self-defense electronic warfare complex (EW) that could operate automatically, without pilot intervention. The TEWS (Tactical Electronic Warfare System) consisted of the analog radar warning receiver Loral AN/ALR-56A, an additional rear-sector radar warning device Magnavox AN/ALQ-128, a Tracor AN/ALE-39 flare/chaff dispenser (in a pod under an external pylon), and a built-in active jamming system Northrop AN/ALQ-135, which enabled the generation of noise and deceptive jamming against fire-control radars, both those known at the time on fighter aircraft (MiG-21, MiG-23, MiG-25) and those guided by radar anti-aircraft missile systems. The device in its initial form operated in the frequency range (approximately): range I – 2000-5000 MHz and range II - 4500-10,000 MHz, together covering the wavelength range of 15.0-3.0 cm. The AN/ALQ-135 antennas (two smaller ones placed one behind the other) were located under the front part of the fuselage, between two larger radio antennas. The AN/ALR-56A operated in the range from 2.0 to 18 GHz and enabled basic classification of detected enemy electronic means. A similar receiver was also an integral part of the ALQ-135. Active jamming was initiated based on the analysis of signals from three different sources: the integral receiver of the ALQ-135 jamming device, the ALR-56A warning receiver, or from the radar, which periodically switched to passive mode, providing TEWS with relevant information. On the other hand, the little-known Magnavox ALQ-128 was not integrated with the rest of the TEWS and served only to support situational display.

Thanks to its modern and powerful Pratt & Whitney F100-PW-100 engines, the F-15A had a thrust-to-weight ratio of 1.4 at a calculated combat weight of 16,160 kg (this was the average weight at which the aircraft entered aerial combat), and 1.2 at a normal takeoff weight of 19,212 kg (with fuel in internal tanks and armament consisting of four AIM-7E missiles, four AIM-9P missiles, and ammunition for the cannon), both in favor of thrust. This provided it with excellent dynamic and maneuvering characteristics. Photo: USAF In the two-seat F-15B aircraft (the prototype's maiden flight was on July 7, 1973), the addition of a second seat required relatively minor modifications, as the F-15A cockpit was very spacious (only the arrangement of some electronic blocks was changed). The mass of the two-seat aircraft increased by about 380 kg. Photo: USAF

Thanks to the installation of in-flight refueling, the time the F-15 can remain airborne is limited only by the psychophysical condition of the crew. There are known missions during which, thanks to multiple refuelings, the aircraft remained in the air for up to 15 hours.

Photo: USAF

of the electronic radio system on the round indicator of the system in the upper right part of the pilot's instrument panel.

Armament

The F-15A/B carried four AIM-7F guided missiles (and from 1979 also AIM-7M) mounted on the lower edges of the box-shaped fuselage, two one behind the other on each side. For maneuvering close-range combat, the F-15A/B was equipped with four AIM-9P missiles. From 1980, the AIM-9L version began to be used, which could be used to attack both from the rear and the front hemisphere of the target (AIM-9P only from the rear).

Spatial capabilities A typical complement to the missiles in "air-to-air" missions was a set of external fuel tanks in the following combinations: one under-fuselage or two under-wing, or all three tanks simultaneously. All three tanks have a capacity of 2,309 liters each, increasing the fuel reserve from 6,750 liters to 13,677 liters. With the tanks installed, the aircraft's ferry range with a navigation reserve (in case of unforeseen flight extension) was 4,160 km. The tactical radius during interception of aerial targets at high altitude was 810 km without tanks and 1,350 km with tanks, and at low altitude - 480 km and 900 km, respectively. Since for airfield alert duty an interception range of about 500 km was entirely sufficient, external tanks were generally not used for this type of mission. In Combat Air Patrol missions—engaging aerial targets while on airborne alert—the aircraft without tanks could remain on station for two hours at a distance of 250 km from the airfield, and with tanks—for four hours at the same distance. The maximum flight endurance of the F-15A/B reached 4.8 hours.

Serial production

Serial production of the F-15 aircraft began on March 1, 1973. By the end of 1973, eight aircraft from the second pre-production batch (F-15A-5-MC, 72-0113 to 72-0116 and F-15A-6-MC, 72-0117 to 72-0120) had been delivered, and in 1974, full-scale serial production was launched. The 1973 budget funded the purchase of 23 F-15A aircraft and 7 two-seat F-15B aircraft, belonging to production series (Block) 7, 8, and 9.

In total, 18 pre-production F-15A aircraft were built in blocks 1 to 6 (4 delivered to Israel), 366 F-15A in blocks 7 to 20 (347 for USAF and 19 for Israel), 2 pre-production F-15B aircraft in blocks 3 and 4, and 61 serial F-15B aircraft in blocks 7 to 20 (59 for USAF and 2 for Israel). In total, 445 Eagles of the first production variant were built. The F-15A/B aircraft remained in regular service until the mid-1990s, when the last were replaced by F-15C/D in the 325th Wing.

Conformal Fuel Tank

After the successful introduction of the F-15A/B into service, McDonnell Douglas focused on eliminating the aircraft's shortcomings. The first issue was the failure to meet the requirement for the aircraft to be able to transfer from the USA to Europe without aerial refueling. The range achieved by the F-15A, 4,160 km, was insufficient. One of the solutions proposed by McDonnell Douglas was to add external tanks, but not the classic underwing types; instead, these would fill the space in the recess between the sides of the fuselage and the wing roots.

The tanks could hold a significant amount of fuel without substantially degrading the aircraft's performance (maximum speed Ma=2, allowable maneuvering overload g+5.5). They were to be made of composites and, in addition to fuel, could also accommodate extra electronic equipment. The use of this type of tank/pod for equipment, called the FAST Pack (Fuel And Sensor Tactical), was proposed as early as the beginning of 1974. A variant designed to carry only fuel was quickly developed

The maximum external load of the aircraft in the air superiority fighter configuration is 6,916 kg and includes three additional fuel tanks and eight guided "air-to-air" missiles. In the case of mounting the AN/ALQ-131 active jamming pod, the aircraft's external load increases to 7,224 kg. The photo shows a two-seat F-15D, whose prototype first flew on June 19, 1979. Photo: USAF and was first used for a test flight on the second TF-15A (F-15B, 72-0291) on July 27, 1974. In September of that year, this aircraft made a non-stop flight from Loring Air Force Base in Maine (northeastern tip of the USA) to Farnborough in the United Kingdom, a straight-line distance of 5,675 km. The flight lasted 5 hours and 25 minutes, and at the time of landing, there were still 2,500 liters of fuel remaining on the aircraft. One FAST Pack tank held 2,912 liters, so the total fuel reserve increased by 5,824 liters (to 19,384 liters), which was enough to achieve a range of about 5,200 km (with an appropriate aeronautical fuel reserve).

Although McDonnell Douglas proposed a number of different FAST Pack variants—with reconnaissance equipment, for Wild Weasel missions against ground-based air defense systems, and for strike missions—the USAF decided to purchase the fuel-only version, essentially as an additional fuel tank. These received the official military designation CFT (Conformal Fuel Tank).

The installation of a second cockpit on the aircraft necessitated the removal of the AN/ALQ-135 active jamming station from its onboard equipment. Placing the station elsewhere was not possible due to electromagnetic incompatibility of the devices. The problem was solved by installing a similar jamming device—the AN/ALQ-131—on the central under-fuselage pylon. Photo: USAF

The use of CFT was not the only change to the fuel system of the new aircraft variant developed from 1976; additionally, Goodyear developed new fuselage tanks, filling a larger portion of its internal volume. The capacity of the internal tanks increased by 1,086 liters (846 kg) to 7,836 liters. The total fuel reserve with standard drop tanks was therefore 14,646 liters, and with CFT tanks up to 20,470 liters, which was sufficient to achieve a transfer range of 5,560 km, fully adequate for a flight from the eastern United States to West Germany.

Modernization of the radar fire control system The main drawback of the AN/APG-63 radar in its previous form was the inability to observe other enemy aircraft and helicopters while tracking a selected target for engagement. Additionally, when observing aerial targets at greater distances, the Eagle's radar could not distinguish individual aircraft flying in a single group.

Therefore, at the end of the 1970s, a plan for the further development of the F-15 was created, which was consistently implemented in the years 1979-1985. It was within this development path outlined at that time that the modernization of certain aircraft systems was undertaken, starting with the fire control system.

The first step in this was to eliminate the two main drawbacks of the radar station mentioned earlier. This became possible thanks to advances in digital computing technology and achievements in this field made in the 1970s. The introduction of a digital computer to control the radar, replacing the analog-digital system, enabled signal processing and the comparison of transmitted pulses with the received echo,

Non-Cooperative Target Recognition The most interesting and at the same time least known device installed on the F-15 C/D MSIP II is the NCTR (Non-Cooperative Target Recognition). The origins of work on this type of device date back to the Vietnam War, when the Americans developed a device to elicit an active response from the Soviet SRO-2 identification system. This device, installed on some F-4Es, facilitated target identification by duplicating the function of the aircraft's own "friend-or-foe" identification system.

The problem was that, in many cases, the identification of certain targets—especially those detected late—was often very difficult. If two aircraft, friendly and hostile, are close to each other or aligned with respect to the interrogating station, errors can occur in the operation of the "friend-or-foe" device. It may happen that a positive response comes from a different aircraft than the one displayed on the radar station screen. Additionally, artificial or natural interference, or simply malfunctions of the identification device, sometimes result in no response from a friendly aircraft. Given the adopted philosophy of target engagement in combat

In aerial operations at the greatest possible distance, the reliable identification of the targeted aircraft was of immense importance. Therefore, a search was initiated for an alternative method of target identification, other than the classical query-response approach.

Work on a device for identification that does not send a query (that is, Non-Cooperative – and does not cooperate) began at the end of the 1970s under the codename "Musketeer." The program was classified as so-called "black," which meant that, officially, it did not exist at all. It was only partially declassified only in 1998, and until recently, no one outside those in the know had heard of it.

The NCTR device is an add-on to the radar, used for digital processing of its signals (independent of the processing performed by the radar's processor), enabling the determination of the number of first-stage compressor blades or last-stage turbine blades if the target is positioned approximately in the front or rear hemisphere (by isolating secondary Doppler frequencies originating from reflections in the inlet duct or exhaust nozzle of the enemy aircraft, from the background of its general echo). Determining the number of blades and their rotational characteristics, and comparing them with a data library stored in the device's memory, allows for the identification of the aircraft type and, consequently, its affiliation. The development of an effectively functioning NCTR only became possible at the end of the 1980s, when computer technology allowed for the use of sufficiently advanced software.

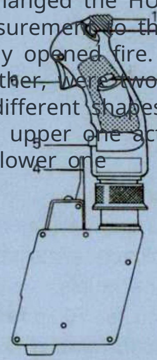
NCTR was introduced on the F-15C/D as part of the MSIP II modernization program and was used for the first time during Operation Desert Storm (1991). Photo: USAF

HOTAS system on the F-15A/B/C/D

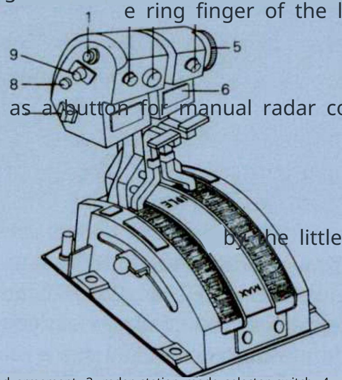
At the front of the stick was a trim button, which, when operated by the thumb up/down and sideways, changed the neutral position of the control stick in the elevator and aileron channels (there were no classic aerodynamic trim tabs, as the F-15 has a non-reversible hydraulic control system). Next to it was also a thumb-operated button that could be pressed and slid down, used to launch external armament (operational only when the main armament switch was on). On the left side of the stick is a switch that can be moved forward and backward or tilted sideways from the stick. It is used to activate the Super Search mode of the radar (first push forward) and the Boresight mode (second push forward) or the Vertical Scan mode (push backward). Tilting the switch sideways from the stick returned it to the long-range search mode (which was active before activating the aforementioned modes typical for air combat). With the radar off (or on the tanker guidance mode), tilting the button sideways disconnected the receiver for in-flight refueling.At the front of the stick was the gun trigger, operated by the index finger. Pressing the button halfway switched the weapon control system to ballistic calculation and changed the HUD to the air-to-air aiming mode with range measurement to the target by radar. Pressing the button all the way opened fire. On the lower part of the stick, one above the other, were two buttons operated by the little finger. They had different shapes, making them easy to distinguish by touch. The upper one activated nose wheel steering on the ground. The lower one

The nose wheel steering was deactivated, and with the landing gear retracted, - the autopilot was disconnected.

On both twin engine control levers, there were additional switches. On the pilot's side, the right engine control lever featured a radio transmission switch; pushing it forward activated transmission on the first radio, while pulling it backward activated the second radio (they operated on different frequencies to enable simultaneous communication on two separate networks). Below that was the aerodynamic brake switch. The third switch from the top was for missile target lock rejection, and below it was a three-position armament switch: medium-range air-to-air missile (forward position), short-range air-to-air missile (middle position), and cannon (rear position). The pilot operated these four switches with the thumb of the left hand. Under the index finger on the right engine lever was a multifunctional four-way switch used to control display ranges and navigation equipment modes, and under the ring finger was a lever for manually designating a target for radar tracking.This lever had the form of a button with a recess into which the ring finger of the left hand was inserted and could be tilted in all directions. On the left engine lever, there was a button for manual radar control in terrain mapping mode, and on the side, a switch for raising/lowering the radar antenna's line of sight, operated by the little finger of the left hand. Even lower was a lever activated by the edge of the hand (as in a karate chop), used for manually launching infrared flares/chaff countermeasures.



Control stick: 1. trim switch; 2. button for launching suspended armament; 3. radar station mode selector switch; 4. button for engaging nose wheel steering; 5. button for disengaging nose wheel steering, and with the landing gear retracted—for disconnecting the autopilot; 6. cannon trigger.



Powerplant control lever: 1. radio transmission button; 2. interrogator activation button; 3. target designation control switch; 4. multifunctional four-way switch for controlling display ranges and navigation equipment modes; 5. radar antenna elevation adjustment knob; 6. button for launching jamming chaff/flare countermeasures (activated with the edge of the hand); 7. armament selection button (cannon, short-range air-to-air missile, medium-range air-to-air missile); 8. button for locking the gunsight reticle (in cannon mode) or releasing the lock-on of a guided short-range missile; 9. aerodynamic brake switch;

reflected from the target. Digital signal processing not only provided better protection for the radar station against electronic countermeasures, but also enabled the separation of individual aircraft flying in tight formations.

Similarly, the system allowed for simultaneous airspace scanning and illumination of a selected target for engagement with the guidance beam for medium-range AIM-7 missiles.

The introduction of a digital radar control processor (in addition to the two existing signal processors), using the existing Cassegrain-type antenna, enabled faster scanning of the airspace. This processor, known as the Programmable Signal Processor (PSP), developed by Hughes and adapted to work as part of the AN/APG-63, appeared at the end of 1979. Its operational memory had a capacity of 96 K, compared to the 24 K memory of the previously used analog-digital processor. In addition, unlike the previous device with a fixed operating algorithm, the new processor had

Software that could be modified was imposed on the F-15A and F-15B aircraft, unnecessarily degrading the aircraft's maneuverability and handling characteristics during close-range air combat. Since preparing a full modernization was expected to take some time and production of the F-15 was not to be interrupted, it was decided to introduce changes gradually on single-seat aircraft produced from 1979 (designated F-15C) and two-seat versions (F-15D). Therefore, the first F-15C, 78-0468, which made its maiden flight on February 26, 1979, in St. Louis, differed from the F-15A only by having a fuel system of increased capacity, adaptation for carrying CFT (FAST Pack) tanks, a reinforced airframe structure, and a slightly modernized landing gear (the last two changes were related to the anticipated higher takeoff weight, with further increases planned for the future). The empty F-15C weighed 13,235 kg, and the two-seat F-15D version – 13,700 kg. This latest variant, in which the same modifications (fuel system installation, structural reinforcement) as those introduced on the combat F-15C were applied to the F-15B, but

Radar stations with the new processor entered production in 1980. F-15C/D aircraft produced in 1980 still had the old radars, but by 1984 they had been upgraded to the final configuration. The radar station continued to operate in the existing modes (there was no Track While Scan mode, only Single Target Track), but its resistance to jamming and resolution were improved. The Raid Assessment Mode (RAM) was also introduced, enabling the separation of aircraft flying in a tight group at a distance of about 75 km. Additionally, the Long Range Boresight Track (LRBST) mode was introduced, which operated like Boresight Track (BST) but could be activated at ranges up to 150 km (BST only up to 20 km). Furthermore, thanks to the new processor, the radar later received software enabling cooperation with AIM-120 missiles.

The third area requiring essential modernization of the F-15 was the engine. The goal was to remove rather troublesome operational limitations.

which, like the F-15B, was not equipped with the built-in AN/ALQ-135 active jamming transmitter, made its first flight on June 19, 1979 (78-0561). The aircraft's tests proceeded successfully, and already in the first half of 1979, serial production of the F-15C (Block 21) was initiated, and in the second half of the same year, the F-15D (also as part of Block 21). In this configuration, 83 F-15C (series 21, 22, and 23) and 14 F-15D (the same production series) were manufactured. Most of them were delivered to the 18th Tactical Fighter Wing at Kadena Air Base in Okinawa, the first PACAF unit equipped with the F-15 and the first combat unit to operate the F-15C/D variant.

Equipped with a modernized radar station, the F-15C and F-15D (unofficially known as the APG-63 PSP) were first deployed to Europe, to the 36th Tactical Fighter Wing, replacing the F-15A and F-15B previously in use there.

In this configuration, meaning not only with the new fuel system but also with the improved radar, a total of 287 F-15C and 70 F-15D were built (together with earlier aircraft of this version, the total production of the F-15C/D, carried out in the years 1979–1985, amounted to

The F-15 can carry three 2,000-pound bombs or 18 500-pound bombs, using multiple ejector racks that allow six bombs per rack. The total weight of the bombs with racks is 4,266 kg. In practice, however, this configuration is not used. Only recently has the aircraft been planned to be armed with JDAM bombs guided by the global satellite navigation system. Photo: USAF

370 single-seat aircraft and 84 F-15D. Of the 287 F-15C mentioned, 221 were taken over by the USAF, 46 were delivered to Saudi Arabia, 8 to Israel, and 2 to Japan (in the latter case, along with a license for their production). Of the 70 F-15D, 34 were taken over by the USAF, 16 were exported to Saudi Arabia, 8 to Israel, and 12 to Japan.

MSIP – Multi-Stage Improvement Program

As a result of conducted studies, a multi-stage modernization program was launched at the end of 1982, aimed at adapting the F-15 to the requirements of the modern battlefield. The program was called the Multi-Stage Improvement Program (MSIP). In its first phase, MSIP I, all operational F-15A/B aircraft were to be brought up to the F-15C/D standard. After standardizing the entire fleet, it was to be fully included in the final modernization program, called MSIP II. At the same time, newly produced F-15C/D aircraft were to have the same configuration as the modernized machines from the outset. However, after preparing the work schedule, it was considered more advantageous to replace the older F-15A/B, which were gradually being transferred to the National Guard, with newly produced F-15C and F-15D, featuring an airframe with reinforced structure (the F-15C/D was approved for maneuvering at g+9, while the F-15A/B was limited to g+7.33). As a result of this decision, purchases of F-15C/D were increased, and ultimately the USAF received 894 air superiority fighters (774 F-15A and F-15C, and 120 F-15B and F-15D) instead of the planned 749. Thus, attention was focused on the MSIP II stage, i.e., on modernizing the F-15C/D, both on the production line and on already manufactured units.

Adapting the F-15 for the simultaneous engagement of multiple aerial targets required the introduction of new weaponry. The AIM-120 missile, equipped with an active radar homing head that does not require target illumination by the fighter's onboard radar beam, was under development. This allows for the launch of multiple AIM-120 missiles at different targets, with each missile independently homing in on its designated adversary. In practice, however, the AN/APG-63 fire control system enabled the launch of two missiles at two different targets, with a time interval necessary to switch to tracking the next target.

In the first half of the 1980s, Hughes developed a new radar intended for the F-15E Strike Eagle variant, which appeared in 1985. It received was designated AN/APG-70. The radar is equipped with the same antenna as the AN/APG-63, but the new control system allows for electronic scanning of the space in elevation, a digital processor with 960 K memory (which is exactly ten times more than the AN/APG-63's 96 K) and three times the processing speed (34.5 million operations per second, compared to 11.4 million operations per second in the previous system). The AN/APG-70 can simultaneously track up to 10 aerial targets within a wide field of view (presumably about 20° at medium range and 60° at short range) in Track While Scan (TWS) mode, introduced for the first time in this system. The APG-70 can cooperate with six launched AIM-120 missiles (each aimed at a different target). The effective SAR (Synthetic Aperture Resolution) system enables not only even better separation of individual aircraft from a group in tight formation, but also the creation of precise terrain maps.

The modernized F-15C air superiority fighter received a fire control system adapted for use with the new guided AIM-7M and AIM-9L missiles, a modified propulsion unit (F100-PW-220), and the capability to carry conformal additional fuel tanks, enabling it to fly non-stop from the USA to Europe. Photo: USAF

However, in the fighter versions, the AN/APG-70 radar variant without the SAR mode was installed, optimized for air combat. This mode was rarely used on fighters, and the radar without these functions was characterized by higher reliability, simpler operation, and lower cost.

The radar automatically changes operating ranges, enabling a full overview of the situation while simultaneously tracking 10 targets (TWS), and by briefly activating the passive mode, it analyzes received jamming signals. If jamming is detected, the radar automatically changes its operating frequency, which can also be changed from pulse to pulse independently of electronic countermeasures (Frequency Agile). The radar uses 32 ground-programmed frequency channels, which change in a pseudo-random order.

The fire control system also employed a new IBM CP 1075 central computer with 128 K memory and triple the processing speed compared to its predecessor. This computer worked with a new control panel in the cockpit. Previously, weapon control on the F-15A, B, C, or D was performed using a classic panel with switches and indicator lights. In the new variant, a multifunctional (i.e., displaying various sequences of information), color Sperry display was introduced.

The main area of subsequent modifications was adapting the aircraft to simultaneously engage multiple aerial targets using "air-to-air" guided missiles equipped with active radar homing heads. In the photo – a two-seat F-15D refuels in the air. Photo: USAF

MPCD (Multipurpose Color Display), and most operations involving the selection of weapon types and their usage parameters are performed from the control stick and the engine throttle lever (DSS), by selecting the appropriate options from the menu on the monitor.

This greatly facilitated the pilot's work; in the previous system, the pilot had to reach for switches and shift their gaze to indicator lights, whereas now, options are quickly selected from the control stick and DSS, and the information on the display is presented in a much clearer manner. The monitor is installed in the lower left part of the instrument panel, to the left and below the previous Vertical Situation Display (VSD).

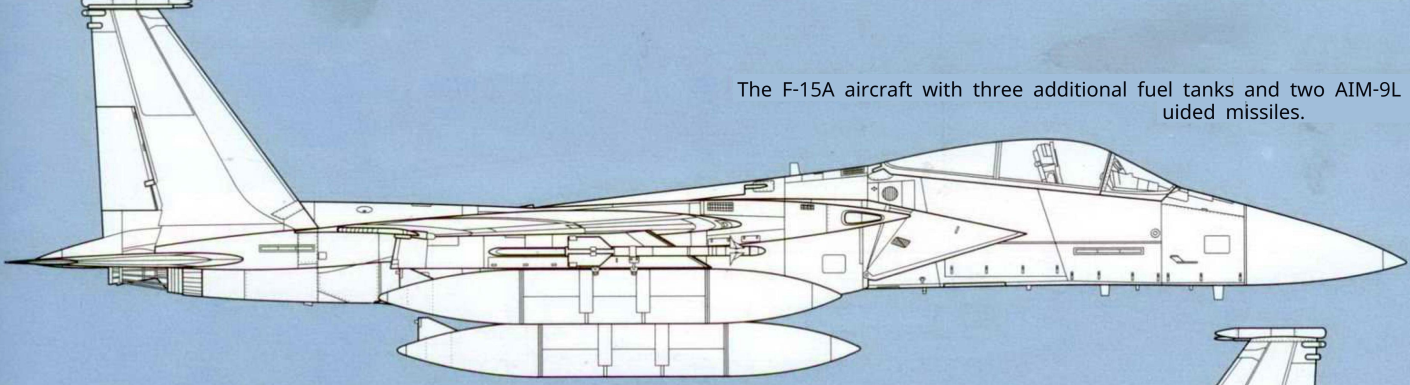
To integrate the new "digitized" radar, the new computer, and the stores management processor, two MilStd-1553B data buses and one MilStd-1776 data bus were installed on the aircraft. The latter enabled the use of new types of guided missiles, AIM-120C, and more recently, AIM-9X.

Electronic Warfare Suite The second element improved under MSIP II was the aircraft's electronic warfare suite. Among other things, a new warning device for enemy radar illumination, the AN/ALR-56C, was introduced. This is a digital version of the analog AN/ALR-56A, with additional enhancements. The frequency range was expanded of the device from the previous 2.0 GHz+18.0 GHz to 300 MHz –25 GHz. Ultra-fast frequency scanning was adapted to detect radars operating at a moderate frequency-hopping rate (detecting pulse-to-pulse frequency-agile radars is presumably impossible). The device's data library was expanded to include the latest types of enemy radar stations, whose operating ranges were analyzed using data collected by electronic reconnaissance aircraft (mainly RC-135), satellites, and human intelligence. The AN/ALR-56C worked in conjunction with the Magnavox AN/ALQ-128 threat analysis device, which also had its own receivers. This latter device remains shrouded in secrecy to this day; even its exact purpose has not been publicly disclosed. Its antennas are located at the tip of the left vertical stabilizer. It is not known whether it was installed on all aircraft or only from the C/D versions, as all serial F-15s intended for the USAF have fairings on the stabilizer.

The aircraft was also designed to be fitted with Tracor AN/ALE-45 flare/chaff dispensers; initially, however, passive countermeasures were considered to be of little effectiveness and a thing of the past. Later, it turned out that strong flares are still effective in protecting against heat-seeking missiles (infrared homing). Ultimately, but only during the MSIP II modernization, AN/ALE-45 was installed on F-15C/D aircraft, including those produced earlier, during their overhauls. Its main purpose was to dispense infrared decoy flares; chaff is now used less frequently, mainly in combination with active countermeasures and appropriate maneuvers. The dispenser is located in the rear, lower part of the fuselage fairings to which the wings are attached. It can be loaded with up to 240 RR-170, RR-180, or RR-188 cartridges (all with chaff) or 120 MJU-7 flares. Another variant is loading 48 MJU-10 flares. The mentioned loads can be combined in appropriate proportions: two MJU-10s take the place of five MJU-7s or ten chaff cartridges.

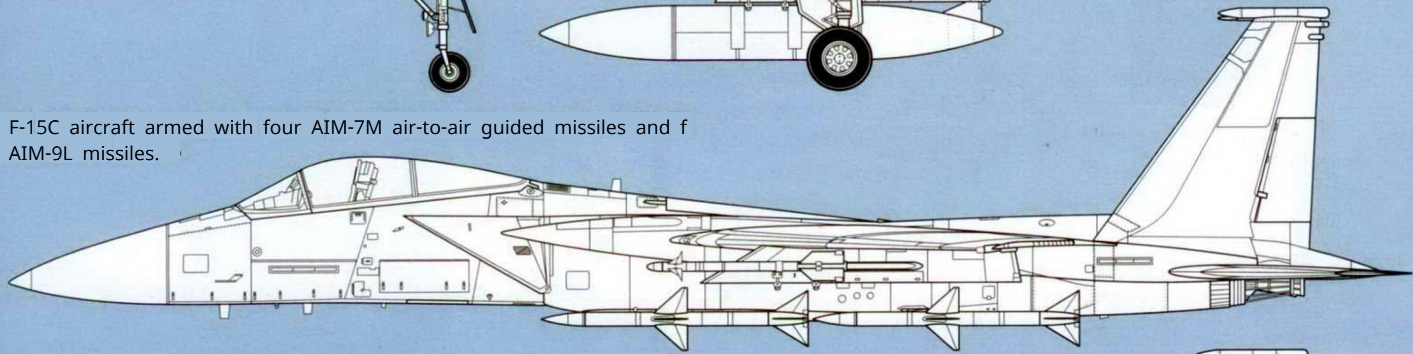
The new active jamming transmitter AN/ALQ-135(V), which generates noise and deceptive jamming, was developed based on the same assumptions

Since the 1990s, 24 F-15 aircraft have been equipped with terminals for the automated Joint Tactical Information Distribution System (JTIDS).

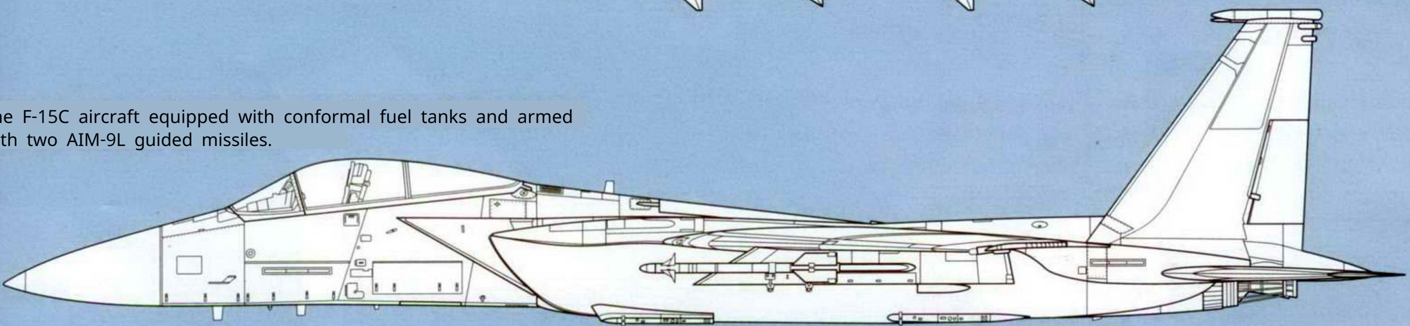


The F-15A aircraft with three additional fuel tanks and two AIM-9L guided missiles.

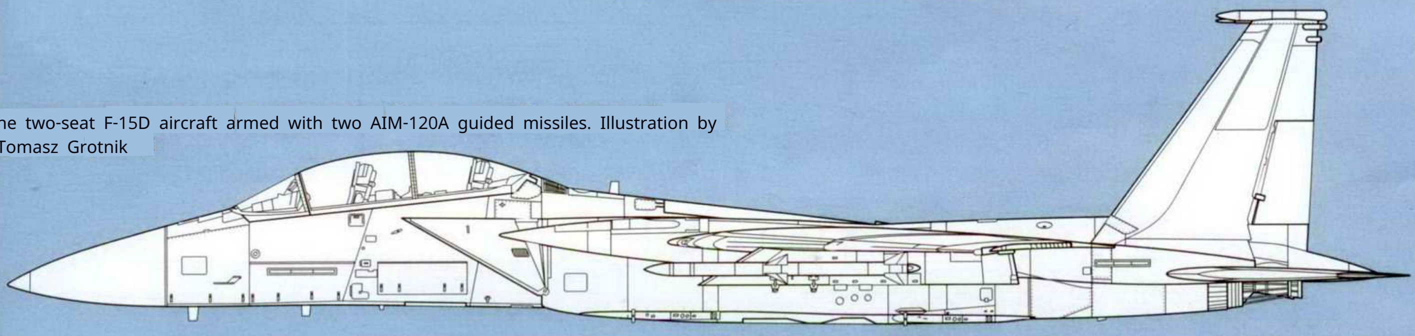
The two-seat F-15B aircraft with an additional fuel tank on the central under-fuselage pylon and two AIM-9L guided missiles.



The F-15C aircraft armed with four AIM-7M air-to-air guided missiles and four AIM-9L missiles.



The F-15C aircraft equipped with conformal fuel tanks and armed with two AIM-9L guided missiles.



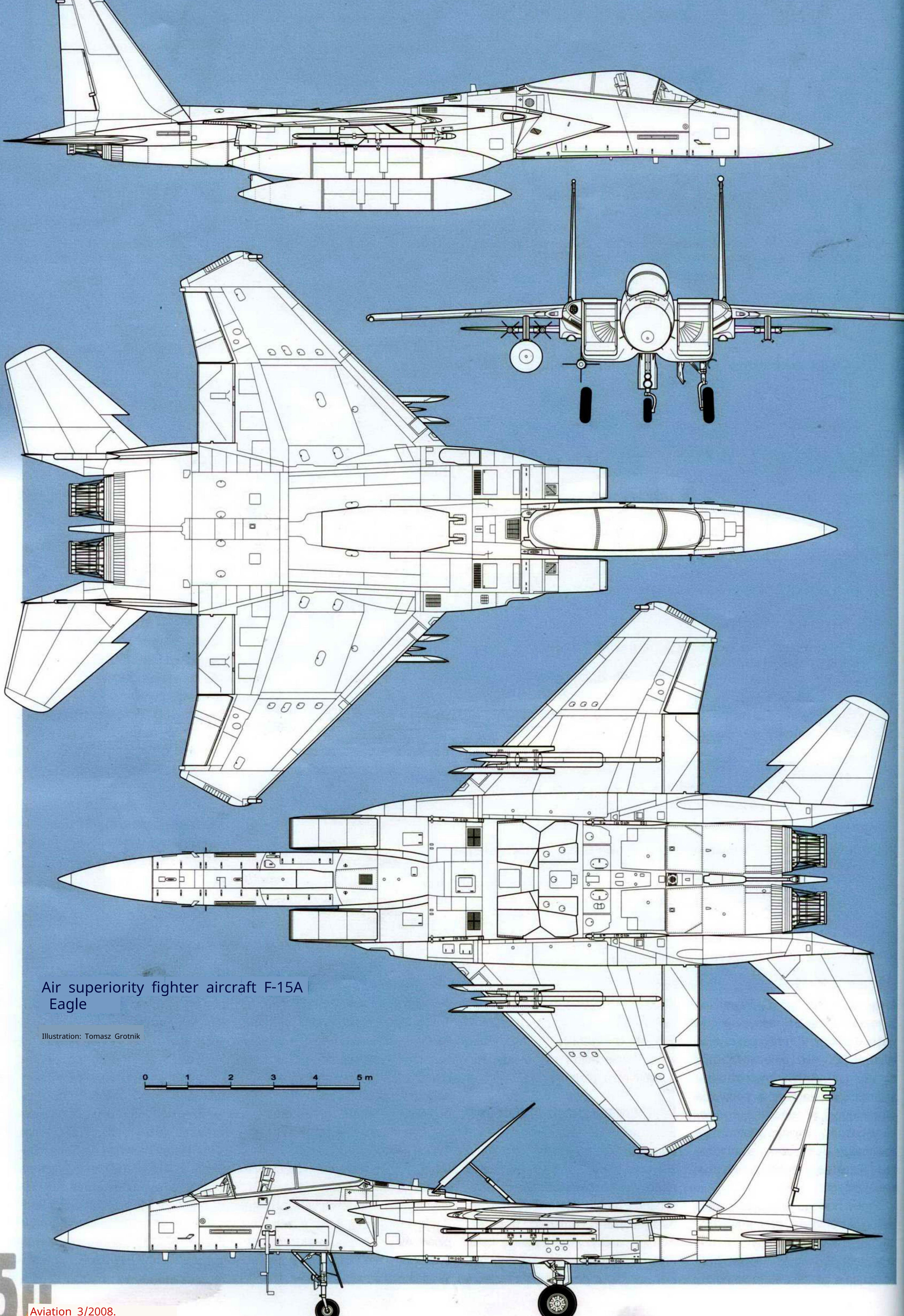
The two-seat F-15D aircraft armed with two AIM-120A guided missiles. Illustration by Tomasz Grotnik

The same applies to the AN/ALR-56C. This necessitated expanding the frequency range to include band III (presumably 8,000 to 18,000 MHz; wavelength from 3.75 to 1.67 cm). The antennas for this band were placed behind the nose landing gear bay and in a special fairing at the base of the right horizontal stabilizer. At the same time, bands I and II were combined in to a single, modified antenna.

Tests of the new electronic warfare complex were conducted on a modernized F-15A in December 1984. In 1985, it was introduced to serially produced aircraft.

MSIP II: F-15C and F-15D (in the latter case, without the AN/ALQ-135(V) jamming transmitter, the components of which in the combat aircraft are located in the cabin behind the pilot's seat).

The refined propulsion system—electronics and digital technology—also helped solve the problems of the F-15 engines. Compressor stall, caused by variable operating conditions of the engine and the intake duct, could be avoided through rapid and precise adjustment of the angle of attack of the compressor blades (guide vanes) combined with the regulation of the amount of injected fuel. This led to the development of the Pratt & Whitney F100-PW-220 engine, in which the regulation of these components was entrusted to an electronic microprocessor operating on advanced software. At the same time, an increase in exhaust gas temperature and, consequently, engine thrust (up to 13,050 kg/128 kN with afterburner) was permitted, which was associated with the elimination of the safety margin in the mechanical-electrical engine control system. In production engines, however, the gas temperature was reduced, thus decreasing the maximum thrust to 10,900 kg (107 kN), slightly less even than the F100-PW-100 engine, but this resulted in increased engine service life and reduced failure rate. Tests of the F100-PW-220 engine were completed in March 1985. Since 1986, these engines have also been installed on earlier F-15C and F-15D aircraft, with either newly produced F100-PW-220 engines or modernized F100-PW-220E engines, converted from F100-PW-100, being installed during overhauls of previously manufactured aircraft.

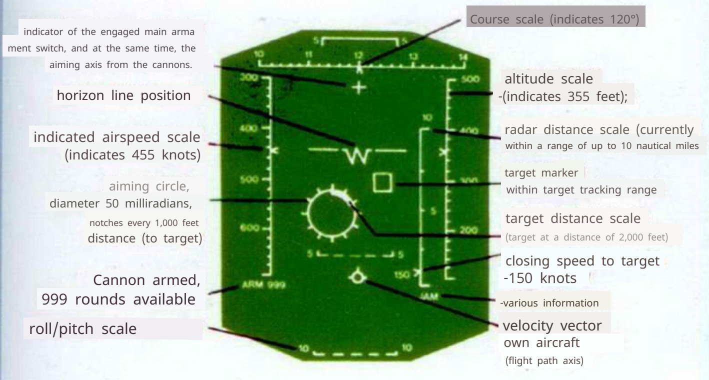


Air superiority fighter aircraft F-15A Eagle

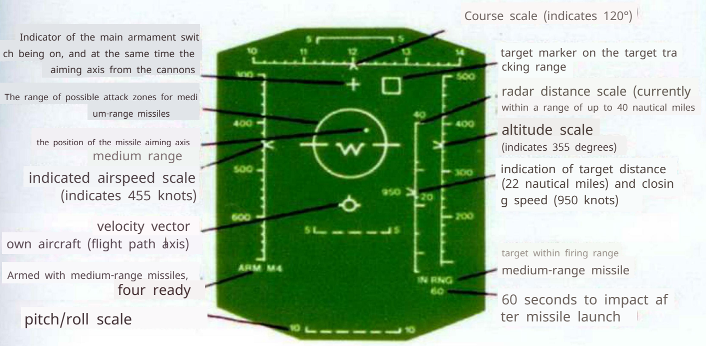
Illustration: Tomasz Grotnik

AN/AVQ-20 Head-Up Display Indicator Imaging

Engaging an aerial target using the M61A Vulcan cannon



Engagement of aerial targets using medium-range guided missiles AI M-7M Sparrow



Tactical and technical data:

Specification	F-15A	F-15C
Crew	1	1
Engine	F100-PW-100	F100-PW-220
Maximum thrust (kN)	64	64
Maximum thrust with afterburner (kN)	112	107
Dimensions		
Wingspan (m)	13,05	13,05
Wing area (m²)	56,49	56,49
Length (m)	19,43	19,43
Height (m)	5,63	5,63
Masses		
Own (kg)	12 700	13 235
Takeoff normal (kg)	19 212	20 185
Combat (kg)	16 160	17 520
Maximum takeoff weight (kg)	25 400	30 845
Fuel reserve		
Internal tanks (1)	6750	7836
Additional tanks (I)	6927	12 634
Total (1)	13 677	20 470
Performance		
Maximum speed at 0 m above sea level (Ma)	1,2	1,2
Maximum speed at 12,500 m (Ma)	2,5	2,5
Climb rate at 0 m above sea level (m/s)	270	275
Normal range (km)	1970	2200
Range with additional tanks (km)	4600	4500/5560
Tactical. Operational radius (km)	900–1350	1200–1800
Takeoff and landing		
Takeoff run (m)	275–970	300–1065
Landing roll (m)	760-1120	850–1075
Max. operational overload (g)	+7.0/-3.0	+7.6/-3.0 MSIP +9.0/-3.0

Afterburner ignition takes about 4 s econds, and afterburner can be eng aged simultaneously in both engines at any speed and altitude (includin g for takeoff).

Production of F-15C/D MSIP II

The first F-15C modernized under the MSIP II program, equipped with the AN/APG-70 radar, F100-PW-220 engines, and a new self-defense suite, but still without AI M-120 missile installation and wit hout the JTIDS terminal, was com pleted on June 20, 1985. On the same day, it made its maiden fli ght and was delivered to the US AF under the serial number 84-0001. This aircraft initiated t he 37th and 38th production s eries, with 30 consecutively pro duced F-15Cs and 5 F-15Ds still lacking both the AN/APG-70 ra dar and F100-PW-220 engines, with only the new self-defense suite introduced. Only the last 48 F-15Cs (41st-42nd production series) and 2 F-15Ds (41st seri es) were the only F-15C/Ds fact ory-equipped with F100-PW-220 engines and AN/APG-70 radars . The reason for this situation was the insufficient number of F100-PW-220 engines (priority f or their delivery was given to t he single-engine F-16C/D). and the delay in the start of pro duction of the AN/APG-70 radar station (which was initially install ed on the F-15E). Production of t he F-15C/D on these aircraft was completed in November 1989. B y November 1989, the total prod uction of F-15C aircraft amounte d to 485 (including 2 F-15J for Ja pan, the rest were built by Mitsu bishi) and the production of the F-15D version reached 104 (inclu ding 12 F-15DJ for Japan).

All of the aforementioned ele ments, however, were gradually installed on aircraft transferred f rom combat units for major ove rhauls and periodic maintenance. The aforementioned modernizat ion work was carried out at th e Warner-Robbins Air Logistic C enter in Georgia (for aircraft b ased in the USA), at the CASA facilities in Getafe, Spain (for U SAFE aircraft), and at the logist ics center at Kim Hue base in South Korea (for PACAF aircraft).

In 1992, after the Gulf War, t he F-15C/D was adapted to carr y AIM-120 missiles. The aircraft can carry eight of these missile s—four on fuselage pylons previ ously used for AIM-7M missiles and four more on universal . air-to-air" medium-range AIM-7 Sparrow.

F-15C air superiority fighter launching a guided missile

Photo: USAF

On LAU-114 launchers in place of AIM-9M missiles. In practice, however, they are combined with AIM-9 in a 4+4 or 6+2 configuration. At the same time, some aircraft (so far only 24 F-15C belonging to the 366th Wing) have been equipped with terminals of the automated Joint Tactical Information Distribution System (JTIDS). The Joint Tactical Information Distribution System is a network of computer terminals that mutually transmit the information they have obtained about the enemy's position, compare and compile it, creating a unified tactical situation display on the monitors of system users.

Despite the end of production of the F-15C/D version in November 1989, the fighter production line was briefly reopened in 1991-1992, when 9 F-15C (series 49 and 50) and 3 F-15D (series 49) were produced for Saudi Arabia, as well as 5 F-15D (series 50) for Israel. All 17 aircraft were already based on the F-15E airframe, with a slightly modified and reinforced internal structure, an engine bay adapted for the installation of power units from both Pratt & Whitney and General Electric, and a slightly different arrangement of some onboard system components.

However, at this point, production of the fighter variant in the United States was definitively ended, although licensed production in Japan continued for some time (this will be described in detail in the section discussing the use of F-15 aircraft in Japan).

F-15C/D Golden Eagle

In total, apart from the newly produced 9 F-15C and 8 F-15D, and apart from 48 F-15C and 2 F-15D of the last series, a total of 427 older F-15A/B/C/D versions were converted to the MSIP II variant (except for the installation of F100-PW-220 engines, as some aircraft still fly with F100-PW-100 engines). In the years 1992-1996, F-15A/B aircraft were also modernized, almost bringing them up to the F-15C/D standard, except that they were not fitted with AN/APG-70 radars and their fuel systems were not upgraded (neither were the internal tanks enlarged nor were the aircraft adapted for CFT tanks).

Since 1996, the F-15 aircraft have been equipped with the AN/APG-63(V)1 radar station, developed since 1994. This is a system optimized for air-to-air combat (lacking SAR capability)

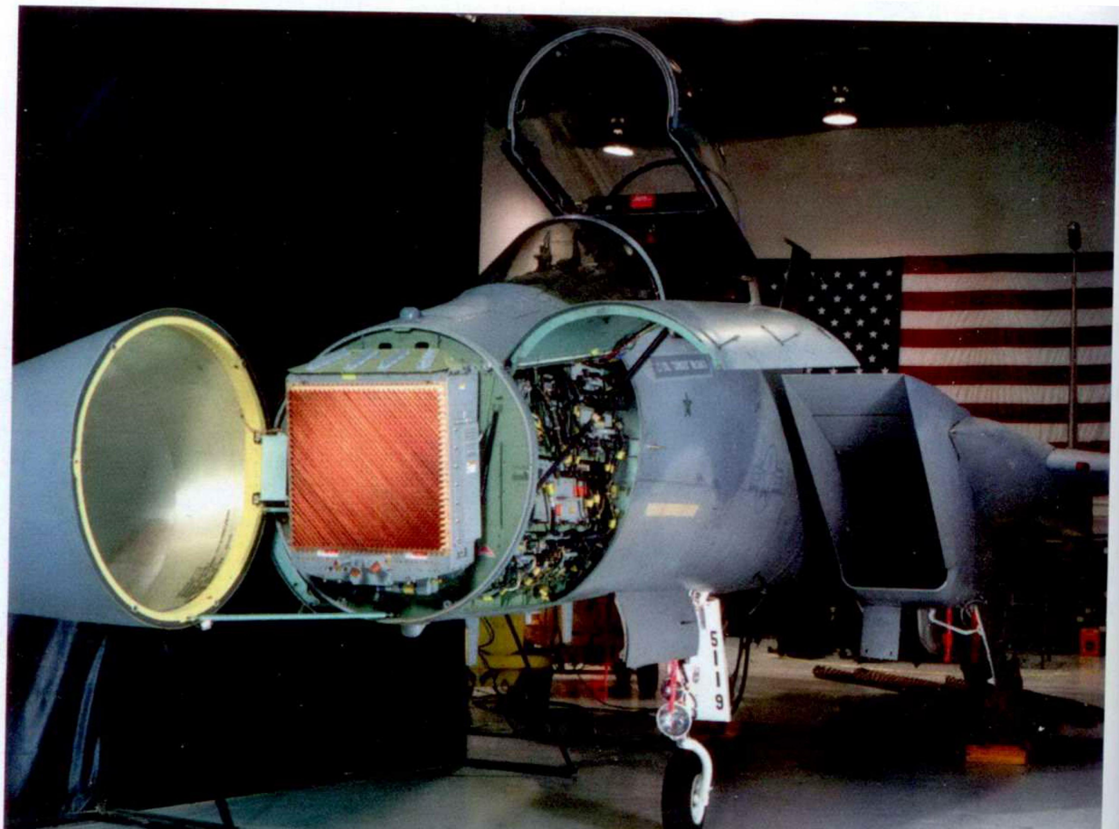
The AN/APG-70 station, in which many older semiconductor electronic components have been replaced with modern, highly integrated circuits. Therefore, these are not exactly the same modules as in the AN/APG-70 station, but even more advanced, built on a new component base. Additionally, the APG-63(V)1 features a more effective built-in self-test system. Compared to the AN/APG-70 radar, this has significantly increased the station's reliability (an average of 120 hours of operation between failures), as well as ensured the maintenance of high radar performance during its operation. The mean time between failures increased nearly tenfold compared to the original AN/APG-63 station. The AN/APG-63(V)1 station has the same air-to-air combat ranges as the AN/APG-70, but it can detect targets with a smaller effective radar cross-section and demonstrates greater resistance to jamming (new software). In this way, the APG-63(V)1 is adapted for combating cruise missiles and small unmanned aerial vehicles.

Since 1996, the AN/APG-63(V)1 fire control radar station, which is optimized for air-to-air combat (lacking SAR capability), has been installed on F-15 fighter aircraft. This is an AN/APG-70 station in which many older semiconductor electronic components have been replaced with modern, highly integrated circuits. Photo: Boeing

In place of the Long Range Search mode typical for the APG-63 radar, the AN/APG-63(V)1 version introduced the Range While Scan (RWS) mode. In this mode, the radar searches for targets at long distances, but in addition, next to the target symbol, numerical data is displayed

The radar provides information about the target's altitude and distance. Starting from a range of 150 km, the radar can be switched to Track While Scan (TWS) mode, which was not available on the standard AN/APG-63. In this mode, up to 10 targets can be displayed.

of targets while simultaneously displaying (in digital form) information about the target's distance, speed, and altitude. However, the TWS range has limitations in terms of the station's observation angles. If we indicate within this range



In the early years of the 21st century, eighteen F-15 aircraft were equipped with AN/APG-63(V)2 fire control radar stations, featuring a square phased array antenna.

Photo: Boeing